

Mappings and Metaphors in Auditory Displays: An Experimental Assessment

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Abstract: Auditory displays are becoming increasingly common, but there are still no general guidelines for mapping data dimensions (e.g., temperature) onto display dimensions (e.g., pitch). This paper presents experimental research on different mappings and metaphors in a generic process-control task environment with reaction time and accuracy as dependent measures. It is hoped that this area of investigation will lead to the development of mapping guidelines applicable to auditory displays in a wide range of task domains. Some keywords in this paper include mapping, metaphor, and guidelines.

Introduction

Sound has been used in human-system interfaces for many years (e.g., [Patterson](#), 1982; [Pollack & Ficks](#), 1954). Until recently, however, the majority of these audible cues have been simple warning sounds. While sonification (the process wherein data is represented directly by one of many possible sound attributes or dimensions) is rapidly maturing (cf., [Kramer](#), 1994a), it is still at the technical and conceptual stage that visual display was a few decades ago. Applications increasingly use sound to convey information, but as with early visual displays, there are currently no standards, and interface designers have usually implemented what sounds "good" to them. In addition, few of the designers have tested their auditory displays within a rigid experimental setting.

The principles for designing effective visual displays are quite generic, for they apply to displaying all sorts of information across a wide variety of task domains (e.g., [Shneiderman](#), 1992; [Tufte](#), 1990). We are now investigating whether

generalizable guidelines for auditory displays can be determined as well. In particular, we are examining metaphors employed in the mapping of data dimensions (e.g., temperature) onto display dimensions (e.g., pitch). For example, representing a rising temperature with a rising pitch seems to be a "natural" choice; it makes intuitive sense. Our mental model of the data space seems to correlate well with the display space. But are there other such natural mappings?

An important consideration involves whether a particular mapping choice has a measurable effect on the performance of a task that relies on the auditory display. Are there better ways to represent temperature? Would another mapping produce faster or more accurate responses? Are some mappings more pleasing or easier to understand? We are especially concerned with representations of common data dimensions that may appear in a wide variety of auditory displays. However, along with the usual temperature, pressure, size, cost, and rate, we are also very interested in how best to display more subjective and effective variables such as "value," "goodness," and "risk" ([Kramer](#), 1994b).

In addition to deciding which auditory feature will represent which data dimension, the direction of the mapping is often critical. The temperature-to-pitch mapping seems natural only as long as rising pitch signals a rise in temperature. We still do not know whether the "inverse" mapping (e.g., rising pitch signals a drop in temperature) would actually affect performance on a task that relied upon that auditory display. Some mappings are based on very common or "dead" metaphors ([Lakoff & Johnson](#), 1980), and we can intuitively decide which direction makes more sense to us. There are many cases, however, where it is difficult to predict which direction of a mapping will produce superior results. If "voltage" were mapped onto "richness" (number of harmonics, for example), should an increase in voltage be represented by an increase or a decrease in the number of harmonics? To really find out which direction of this mapping is more effective, we need a performance measure based on a task that requires the auditory display.

Procedure

To measure performance in a task setting and still pursue generalizable, task-independent mapping results, we have developed a generic process control (a "crystal" factory) as our experimental environment (cf., [Gaver, Smith & O'Shea, 1991](#)). This way we can include virtually any type of data dimension (including effective variables) and have complete control over both how the variables interact and how they are displayed.

Participants sit in a sound-attenuated room where they listen to the auditory display via headphones, and they respond to the display by using a response box consisting of rows of large buttons. Each participant receives a basic description of the Crystal Factory and is trained to associate each data dimension (e.g., the pressure of the crystal formation process) with a dimension of the auditory display (e.g., "brightness" of a sound). This training involves both a verbal description and auditory practice.

The actual environment involves four variables at this time with each variable controlling one aspect of the audio output. The data values all remain at their starting points for several seconds, and one of the variables then increases or decreases. The listener hears this change as a period of steady state in the factory process followed by a change in one of the process parameters. This sonic transition is explained to the listener as a period of "normal operations" followed by "something going wrong." In order to preserve the crystal quality, the listener is required to make an appropriate control action as quickly as possible by using the labeled response buttons. For example, if the temperature drops (perhaps represented by an increased loudness of the sound), then the correct response would be to press the "Heater On" button (see [Fitch & Kramer, 1994](#), for a similar design).

Subjects all hear the same actual sounds but are required to make different responses depending on their training condition. There are several different trial types that vary the starting values of the variables and the variable that changes. Each trial

type is repeated several times within a block of trials, and each participant completes several blocks of trials. The independent variables include the particular mapping that the listener had been trained to hear and the actual variable that changes on a given trial. The performance measures include response time (RT) and accuracy. In addition, after each trial, the participant is asked to say which parameter of the process changed in order to ensure that he or she is paying attention to the metaphor and not simply mapping the auditory display parameter directly to the related response button.

Predictions

This work is still underway due to delays caused by technical difficulties encountered while setting up the study. Full details of the results will be presented at ICAD. However, we do present some definite predictions. Mappings based on stronger or more natural metaphors will result in faster and more accurate control reactions. These mappings should also be learned faster, which will lead to increased improvement in performance across the blocks of the experiment. For some mappings, there will also be a particular direction that results in better performance (e.g., rising temperature mapped to rising as opposed to falling pitch). These results should complement the findings in the area of stimulus-response compatibility (e.g., [Proctor & Reeve, 1990](#)) and cross-modality matching ([Melara & O'Brien, 1990](#); [Walker & Ehrenstein, 1996](#)).

Implications

It is likely that a number of the most "successful" mappings will be the ones that have most often been used in auditory displays. However, we expect to discover other good mappings, and, in particular, we will try to display variables that have great possibilities but have not often been represented with sound. The strong emotive power of music (cf., [Révész, 1954](#)) suggests that effective variables are perfect examples of information that may be difficult to describe with words or

pictures but that will be easily recognized with sound.

This research is a first step in attempting to quantitatively compare different auditory display setups. We are careful to note that the design of an effective auditory display will always require practice and good judgment. However, the extension of the present research may help to identify guidelines for representing data with sound, which will hopefully apply across a wide range of task domains.

ICAD Presentation

For the presentation at the International Conference on Auditory Display, we plan to discuss the actual results that we obtain. We will present several examples of the sounds used in the experiment so that the audience can get a firsthand sense of our mapping conditions. In particular, we will play examples of the most natural mappings as well as some of the more ambiguous mappings and discuss how performance varied in the different conditions. Further implications will be addressed, and we hope to generate a lively discussion about the possibilities of general guidelines for the use of mappings and metaphors in auditory displays.

References

Fitch, T., & Kramer, G. (1994). Sonifying the body electric: Superiority of an auditory display over a visual display in a complex, multivariate system. In G. Kramer (Ed.), Auditory Display: Sonification, Audification, and Auditory Interfaces. Santa Fe Institute Studies in the Sciences of Complexity, Proc. Vol. XVIII (pp. 307-325). Reading, MA: Addison-Wesley.

Gaver, W., Smith, R. B., & O'Shea, T. (1991). Effective sounds in complex systems: The ARKola simulation. Proceedings of CHI'91, held April 28-May 2, 1991, New Orleans. Reading, MA: ACM Press/Addison-Wesley.

Kramer, G. (1994a). An introduction to auditory display. In G. Kramer (Ed.), Auditory Display: Sonification, Audification, and Auditory Interfaces. Santa Fe Institute Studies in the Sciences of Complexity, Proc. Vol. XVIII (pp. 1-77). Reading, MA: Addison-Wesley.

Kramer, G. (1994b). Some organizing principles for representing data with sound. In G. Kramer (Ed.), Auditory Display: Sonification, Audification, and Auditory Interfaces. Santa Fe Institute Studies in the Sciences of Complexity, Proc. Vol. XVIII (pp. 185-221). Reading, MA: Addison-Wesley.

Lakoff, G., & Johnson, M. (1980). Metaphors we live by. Chicago: University of Chicago Press.

Melara, R. D., & O'Brien, T. P. (1990). Interaction between synesthetically corresponding dimensions. Journal of Experimental Psychology: General, 116(4), 323-336.

Patterson, R. D. (1982). Guidelines for auditory warning systems on civil aircraft. Paper No. 82017. Civil Aviation Authority, London.

Pollack, I., & Ficks, L. (1954). Information of elementary multidimensional auditory displays. Journal of the Acoustical Society of America, 26, 155-158.

Proctor, R. W., & Reeve, T. G. (Eds.) (1990). Stimulus-response compatibility: An integrated perspective. Amsterdam: North Holland.

Révész, G. (1954). Introduction to the psychology of music. Norman, OK: University of Oklahoma Press.

Shneiderman, B. (1992). Designing the user interface: Strategies for effective human-computer interaction (2nd ed.). Reading, MA: Addison-Wesley.

Tufte, E. (1990). Envisioning information. Graphics Press.

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